5-2010

Registration of 'Warrior', 'Scout', and 'Chief' Indiangrass

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ABSTRACT

'Warrior' (Reg. No. CV-252, PI 655523), 'Scout' (Reg. No. CV-253, PI 655524), and 'Chief' (Reg. No. CV-254, PI 655525) indiangrass [*Sorghastrum nutans* (L.)] Nash were developed for improved yield and forage digestibility by USDA-ARS and the University of Nebraska for use in the central Great Plains and the Midwest USA. Warrior was tested as Oto C3 and was developed by means of both half-sib family selection and restricted, recurrent phenotypic selection (RRPS). Scout and Chief which were tested as NE54 C2 and Holt × Oto Early C2, respectively, were developed by RRPS. Warrior is adapted to USDA Plant Hardiness Zone (HZ) 5 and the upper part of HZ 6 in the Great Plains and Midwest. It produces forage with high in vitro dry matter digestibility (IVDMD) that results in improved animal gains when utilized by beef cattle in well managed grazing systems in regions where it is adapted. Scout is adapted to HZ 5 in the Great Plains and Midwest, USA. It produces significantly greater forage yields than other adapted indiangrass cultivars when grown for hay in the western part of its adaptation region. Chief is adapted to HZ 4 and the upper half of HZ 5. It produces significantly greater forage yields than the other available HZ 4 cultivars. Warrior, Scout, and Chief represent the second generation of indiangrass cultivars developed for use in production agriculture. In the regions where they are adapted, these cultivars can be used in pure stands or in multispecies mixtures with other grasses.

Indiangrass is a C_4 plant species that is native to temperate North America east of the Rocky Mountains (Hitchcock, 1971; Mitchell and Vogel, 2004). It was one of the primary tall grasses found in the prairies and plains of the USA. Cultivars of indiangrass have been developed for use in warm-season pastures and for conservation plants where it has been typically planted in multispecies mixtures with big bluestem (*Andropogon gerardii* Vitman), switchgrass (*Panicum virgatum* L.), and little bluestem [*Schizachyrium scoparium* (Michx.) Nash]. To date, its primary use in pastures has been in the Great Plains and Midwest states of the USA.

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Abbreviations: HS, Half-sib family selection; HZ, Plant Hardiness Zone; IVDMD, in vitro dry matter digestibility; PAR, Plant Adaptation Region, RRPS, Recurrent, restricted, phenotypic selection.

Published in the Journal of Plant Registrations 4:115–122 (2010).
doi: 10.3198/jpr2009.09.0554crc

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Adaptation areas for indiangrass cultivars and strains are determined by latitude or USDA Plant Hardiness Zones (Cathey, 1990) and ecoregion (Mitchell and Vogel, 2004). Thermal and moisture zones characterize conditions for plant growth in a geographical area known as an ecoregion (Bailey, 1995). Indiangrass populations from different latitudinal zones within an ecoregion can be differentiated by growing the populations in common nurseries or gardens located at latitudes within the ecoregion (McMillan, 1959a, 1959b). When evaluated at Lincoln, NE, indiangrasses from southern latitudes flowered late while those from northern latitudes flowered early (McMillan, 1959b). This photoperiod response affects both biomass yield and winter survival. If southern ecotypes are moved too far north, they will not survive the winters and moving northern ecotypes south generally results in decreased biomass yield. Consequently, the indiangrass cultivars that have been developed to date are adapted to specific Plant Hardiness Zones (HZ) or latitude (Mitchell and Vogel, 2004). Plant Adaptation Regions (PAR) for native perennials were developed by Vogel et al. (2005) by overlaying the USDA Plant Hardiness Zone (Cathey, 1990) map with Bailey's Ecoregion map (Bailey 1995, 1997). The resulting Plant Adaption Region Map (Vogel et al., 2005) can be used to define adaptation region of both native and introduced perennial plants and will be used in this report to define cultivar adaptation regions.

Indiangrass is a cross-pollinated allopolyploid ($2n = 40$) with normal diploid segregation at meiosis (Mitchell and Vogel, 2004). Indiangrass is cross-pollinated by wind, it is largely self-incompatible, but some plants produce a limited quantity of seed when self-pollinated. The cultivars Nebraska

54, Oto, Holt, and Osage were confirmed to have 40 chromosomes by Riley and Vogel (1982). The breeding systems that can be used to developed indiangrass cultivars are those that have been developed for other cross-pollinated perennial grasses (Vogel and Pedersen, 1993). Much of the initial breeding work with indiangrass involved the ecotype selection procedure (Vogel and Pedersen, 1993), in which germplasm accessions for the intended region of use are collected from native sites, evaluated in nursery trials, and a superior accession is selected and increased as a single source-identified cultivar. The released cultivars Llano, Lometa, Nebraska 54, Rumsey, and Cheyenne were developed by this breeding method (Alderson and Sharp, 1994). The cultivar Tomahawk was developed by combining several selected accessions and increasing them together to produce a synthetic cultivar. The cultivars Holt, Oto, and Osage were developed by mass or family breeding systems (Alderson and Sharp, 1994). None of the previously released indiangrass cultivars were selected or evaluated for forage digestibility in forage or pasture trials.

The primary objective of the indiangrass breeding program was to develop indiangrass cultivars with improved forage quality and yield for use in warm-season pastures in HZ 4 and 5 in the eastern Great Plains and Midwest states. The breeding program for the cultivars was initiated with a study to determine the heritability of forage yield and IVDMD in indiangrass (Vogel et al., 1981a, 1981b). The results of the heritability study in which the cultivars Oto and Holt were used as reference populations indicated that there was significant variation in these indiangrass populations for both forage yield and IVDMD and genetic gains could be made by simultaneous breeding for both traits (Vogel et al., 1981a). In both the Oto and Holt populations, phenotypic correlations between forage yield and IVDMD were not significant (Vogel et al., 1981a).

The base population used to develop Warrior was the cultivar Oto which was released in 1970 (Newell, 1974). Oto, which was developed from 100 plants from 15 accessions made from native prairies in southern Nebraska and eastern Kansas, has a broad genetic base and has proven to be well-adapted in the USA over a broad geographic area in the Central Plains and the Midwest in HZ 5 and 6. Scout was developed from the source identified cultivar, Nebraska 54, which was collected from native stands in Jefferson County Nebraska and increased by seed producer Harold Hummel. Nebraska 54 has been a useful cultivar in south central Nebraska and north central Kansas, but breeder or source seed of this cultivar is no longer available. Hence, a need existed to replace this valuable adapted cultivar with a cultivar with similar adaptation characteristics but with improved forage traits. Holt was developed by mass selection from ecotypes collected in north-eastern Nebraska and is 20 d earlier in maturity than Oto (Newell and Conard, 1968; Vogel et al., 1981a). Holt has been a useful cultivar in HZ 4, but its yield is limited by its early maturity. A Holt × Oto population was used as the base population for Chief.

Methods

All selection, polycross, and seed increase nurseries used in the development of Warrior, Scout, and Chief indiangrass were located on the University of Nebraska's Agricultural Research and Development Center (ARDC) located near Mead and Ithaca, NE (41°09′ N. lat., 96°25′ W. long.). In the heritability study nursery and all other space-transplanted nurseries described in this report, rows and plants within rows were spaced on 1.1-m centers and the following cultural practices were used. Space-transplanted nurseries were established by transplanting greenhouse grown seedlings into the selection nurseries. The nurseries were cultivated between plants with 0.6-m-wide roto-tillers creating 0.4- × 0.4-m mini-plots for individual plants. Nurseries were fertilized annually with approximately 112 kg ha^{-1} N and, herbicides and hand weeding were used for weed control. Space-transplanted nurseries were mowed or burned each spring to remove the accumulated biomass from the previous year. No data were collected the establishment year. Forage harvests for yield and quality analyses were made in Year 2 or 3 and selections were made in Year 4. In each generation, two ramets of selected genotypes were transplanted at random into isolated polycross nurseries. Seed was harvested from each individual plant in a polycross nursery in Years 5 or 6 and an equal amount of seed was bulked from each of the genotypes and the bulked seed was used to start the next breeding cycle. Each breeding generation took approximately 5 yr but varied depending on weather conditions.

Breeding History

Warrior

The Oto component of the heritability study (Vogel et al., 1981a, 1981b) served as the Cycle 1 (C1) selection nursery. Half-sib family selection (HS) was used for the first breeding cycle followed by two breeding cycles or generations of RRPS (Vogel and Pedersen, 1993). The primary selection criteria in all breeding cycles were forage yield and IVDMD of plant samples collected at inflorescence emergence or post-anthesis. In C1, the selection criteria were that the half-sib family mean forage yield and IVDMD had to be equal or greater than the nursery mean, and the digestible yield per plant had to be greater than 350 g per plant. In C1, a half-sib family plot was a single row of four plants. The heritability–selection nursery had two replicates in a randomized complete block design. In 1976, five tillers were collected from each plant and were used for quality analyses. Yields were harvested at the end of the growing season in October when the plants were mature. The 1976 data on the 146 half-sib families were used to select parent plants whose half-sib progeny had high mean forage yields and high forage IVDMD (Table 1). Two ramets from each of 29 selected Oto indiangrass parent plants were moved to an isolated polycross nursery. An equal amount of seed was bulked from each genotype to start C2.

In breeding Cycles 2 and 3, the RRPS breeding system was used because of the success Burton (1974) had in improving bahiagrass (*Paspalum notatum* Flüggé) yields. The C2 nursery had 742 plants (53 rows with 14 plants per row). In 1980, the plants in the nursery were visually evaluated prior to forage harvest and approximately three of the best plants per 14-plant row (rows were the RRPS selection unit) were selected for forage harvest. Samples were obtained by har-

Table 1. Selection nursery means and SDs† for forage yield and in vitro dry matter digestibility (IVDMD), and Nebraska Index (NI) for each breeding cycle in the Oto indiangrass population in the development of the cultivar Warrior.

	Population size	Harvested plants	Forage yield	IVDMD	NI
	n		g plant^{-1}	g kg^{-1}	
Cycle 1 (HS)					
Selection nursery families	146		916	361	
Selected parents	29		1038	377	
Cycle 2 (RRPS)					
Selection nursery plants	742	150	1221 (218)	388 (47)	0.0
Selected plants	39		1398 (186)	429 (36)	1.7
Cycle 3 (RRPS)					
Selection nursery	875	266	694 (215)	658 (28)	0.0
Selected plants	38		872 (38)	683 (20)	1.7

†SD = standard deviations in parenthesis.

vesting approximately 4 to 6 tillers per plant at a 10-cm cutting height for IVDMD analysis. Traits considered in the visual evaluation included vigor, absence of disease, and potential forage and seed production. Plants selected for harvest were sampled and harvested on 30 Sep. and 1 Oct. 1981. In the spring of 1983, plants were selected by means of a selection index (NI = Nebraska Index) which gives equal weight to forage yield and digestibility (see below equation).

$$NI = [(\text{yield} - \text{mean yield})/\text{yield } s] + [(\text{IVDMD} - \text{mean IVDMD})/ \text{IVDMD } s];$$

in which *s* is the standard deviation.

Thirty-nine C2 plants were selected for polycrossing on the basis of the 1981 data (Table 1). The C3 selection nursery which contained 875 plants was established in 1986. The procedures used in the C3 nursery were the same as those used in C2 except the number of plants per row (*n* = 17 or 18) differed slightly and the plants were sampled and harvested in late August rather than late September. Thirty-eight C3 plants were selected for polycrossing based on data collected in 1988 (Table 1). Seed from the C3 polycross nursery was used to establish a seed increase nursery that produced Syn 2 seed for use in yield tests and pasture trials. Warrior was evaluated and tested as Oto C3.

Scout

The breeding work was initiated in 1977 with certified Nebraska 54 seed used to produce seedlings for the C1 selection nursery. The breeding method was RRPS using procedures described previously. In each breeding cycle, the selection nurseries had about 900 plants (Table 2). Following the establishment year, about one-third of the plants in the nursery were visually selected for vigor and absence of disease. These plants were sampled and harvested for forage yield after heading and to determine IVDMD. The primary selection criterion was the selection index described previously in which harvested forage yield and IVDMD received equal weight. In each generation or breeding cycle, selected plants were intermated in isolation to produce seed to start the next generation of selection. Two breeding cycles or generations were completed in the development of Scout. After the second breeding generation was completed, seed from the polycross nursery was used to plant an increase nursery that produced seed (Syn 2) used in small plot evaluation trials and a replicated grazing trial. Scout was evaluated and tested as NE 54 C2.

Chief

Chief was developed by one generation of breeding for improved forage yield followed by an additional generation or cycle of breeding for both improved forage yield and forage digestibility as measured by IVDMD. The base population was a Holt × Oto Syn 2 population developed by Dr. L.C. Newell, retired and deceased USDA-ARS grass breeder. His intent in the development of this population was to use it to develop a cultivar that was intermediate in maturity to the cultivars Oto and Holt. The Holt × Oto synthetic 1 (Syn 1) population was developed from seed harvested from Holt plants exposed to Oto pollen in an open-pollinated Holt × Oto crossing block. The breeding work was initiated in 1973 with the establishment of a Holt × Oto Syn 2 selection nursery that contained about 680 plants. In 1976, heading date was determined on every plant in the nursery and every plant was harvested for forage yield after heading. Plants also were harvested after heading in 1977. There was a wide range in heading date among the plants. Two sets of plants were selected on the basis of 2-yr forage yields, and heading date and were used to establish the Holt × Oto Early and Holt × Oto Late breeding populations, respectively. Mean heading date of the two sets differed by 14 d. The Holt × Oto Early population was used in a subsequent breeding cycle (C2) to develop Chief. The Holt × Oto Early C2 selection nursery had about 840 plants. Following the establishment year, about one-third of the plants in the nursery were visually selected for vigor and absence of disease (Table 3). These plants were sampled for IVDMD and harvested for forage yield after heading. The primary selection criterion was the selection index described previously. In each generation or breeding cycle, selected plants were intermated in isolation to produce seed to start the next generation of selection. After the second breeding generation was completed, seed from the polycross nursery was used to plant an increase nursery that produced seed (Syn 2) used in small plot evaluation trials. Chief was evaluated and tested as Holt × Oto Early C2.

Forage Trials

Multiyear small plot forage evaluation trials were established at Mead, Clay Center, and Concord, NE, to evaluate

Table 2. Selection nursery means and SDs† for forage yield, in vitro dry matter digestibility (IVDMD), and Nebraska Index (NI) for each breeding cycle in the Nebraska 54 indiangrass population in the development of the cultivar Scout.

	Population size	Harvested plants	Forage yield	IVDMD	NI
	n		g plant^{-1}	g kg^{-1}	
Cycle 1 (RRPS)			(2 yr total)		
Selection nursery	928	308	2323 (435)	476 (28)	0.0
Selected plants	66		2530 (542)	496 (28)	1.73
Cycle 2 (RRPS)			1 yr		
Selection nursery plants	871	170	785 (122)	472 (33)	0.0
Selected plants	44		944 (86)	52.2 (24)	2.14

†SD = standard deviations in parenthesis.

Table 3. Selection nursery means and SDs† for forage yield, in vitro dry matter digestibility (IVDMD), and Nebraska Index (NI) for each breeding cycle in the Holt × Oto early indiangrass population in the development of the cultivar Chief.

	Population size	Harvested plants	Forage yield	IVDMD	NI
	n	*N*	g plant^{-1}	g kg^{-1}	
Cycle 1					
Selection nursery	682	621	1015 (387)		
Selected plants	54		1514 (307)		
Cycle 2					
Selection nursery	836	178	898 (164)	400 (40)	0.01
Selected plants	61		1012 (136)	434 (30)	1.54

†SD = standard deviations in parenthesis.

the forage yield and quality of indiangrass experimental strains in comparison with their parent cultivars and other cultivars. Concord and Mead are in the Prairie Parkland Temperate or tall grass prairie ecosystem in HZ 4 and 5 (PARs 251-4 and 251-5), respectively, whereas Clay Center is in the transition zone between the tall grass and mid-grass prairie or Great Plains Steppe ecoregions in HZ 5 (Fig. 1). Trials were planted in 1999 using a small plot drill into clean, firm, conventional seedbeds. The herbicide imazapic {2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-5-methyl-3-pyridinecarboxylic acid} was applied at the rate 0.28 kg a.i. ha^{-1} after planting. No fertilizer was applied the establishment year. In the spring of the following years, the previous year's accumulated biomass was removed by burning or mowing. In each post establishment year, N fertilizer was applied in the spring at the rate of 112 kg ha^{-1} N, except 2001, when 30 kg ha^{-1} N was applied at Clay Center and Concord. In the post-establishments years, a herbicide mixture of 1.1 kg a.i. ha^{-1} of 2,4-D low volatile ester [isocetyl (2-ethylexyl) ester of 2,4-dichlorophenoxyacetic acid] and 2.2 kg a.i. ha^{-1} metolachlor [2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-(2-methoxy-1-methylethyl) acetamide] was applied in the spring to each trial for broad-leaf and grassy weed control. The trials were managed for quality hay production and were harvested when plants in the sward plots were in the pre-boot or elongation stage of development. Harvest dates varied with location and year but were the third or fourth week of July. A regrowth harvest was taken after a killing frost. Prior to harvest, the plots were sampled by cutting intact tillers at a 10-cm height from 4 or 5 locations within a plot with hand sickles. These samples were used for dry matter determinations and for forage quality analysis. The plots were harvested with a flail type forage harvester that cut a 0.9-m-wide swath out of the center of each 1.5-m-wide plot. The plots were 3 m in length and separated on the ends by a 1.5-m-wide alley. Plots were harvested for forage yield and quality in 2001 and 2002. Harvest 2 or regrowth yields were taken only in 2002 because of drought in 2001.

Pasture Trials

Two experimental strains, NE54 C2 (Scout) and Oto C3 (Warrior), were compared with their base populations of Nebraska 54 and Oto in a replicated grazing trial. In brief, experimental units were three replicates of 0.4-ha pastures of each strain or cultivar that were seeded in a randomized complete block design in June 2003 near Mead, NE. Pastures were fertilized with 112 kg ha^{-1} N in the spring of 2004 and 2005 prior to grazing. Each pasture was stocked with three crossbred yearling steers in June 2004 and 2005 and grazed for 47 and 85 d, respectively.

Laboratory Analyses

The Tilley and Terry (1963) procedure was used for IVDMD analyses for the selection nurseries. In 1999, our laboratory converted to a filter bag method of determining IVDMD using the procedures described by Vogel et al. (1999). The filter bag IVDMD analyses were used to determine the IVDMD of calibration samples that were used to develop near infrared reflectance spectroscopy (NIRS) prediction equations that were used to analyze the forage samples from the multisite yield tests and the pasture study. Harvested samples were dried in a forced-air oven at 50°C to a constant weight and dry weight determined. Dried samples were ground to pass a 2-mm screen in a Wiley mill and a 1-mm screen in a cyclone mill (Thomas-Wiley Mill Co., Philadelphia, PA) and scanned on a near-infrared reflectance spectrophotometer (NIRS; Model 6500, Silver Spring, MD). NIRS calibration sets for IVDMD and N were chosen by cluster analysis of the reflectance data (Shenk

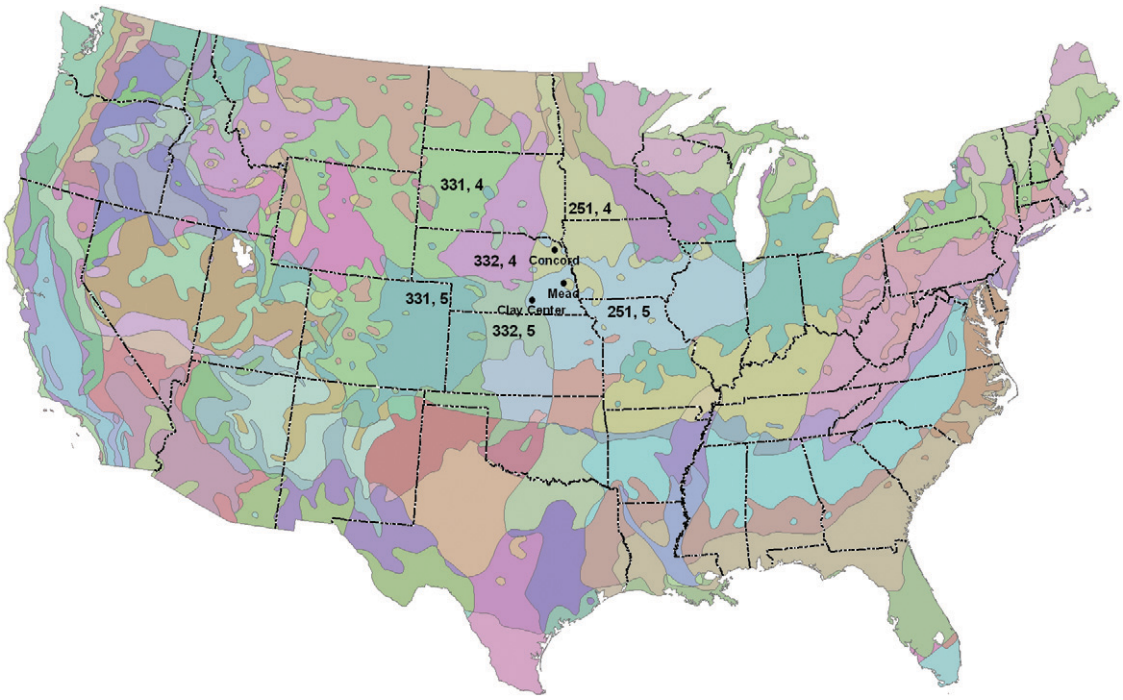

Figure. 1. Plant Adaptation Regions (PAR) and test site locations where indiangrass performance trials were conducted during the period 1999–2005. PAR 251-4 and PAR 251-5 = Prairie Parkland Temperate HZ 4 and HZ5, respectively; PAR 332-4, PAR 332-5 = Great Plains Steppe HZ 4 and HZ5, respectively. Prairie Parkland Temperate is equivalent to the tallgrass prairie ecoregion.

and Westerhaus, 1991). Calibration samples were analyzed in triplicate for IVDMD with the ANKOM Rumen Fermenter (ANKOM Technology Corp., Fairport, NY) on the basis of the procedures described by Vogel et al. (1999). Nitrogen concentration (N) was determined by the LECO combustion method (Model FP 428 and FP 2000, LECO Corp., St. Joseph, MI) (Watson and Isaac, 1990; Bremner, 1996). Laboratory means were used to develop calibration equations by partial least squares (Shenk and Westerhaus, 1991). Values of IVDMD and N were predicted with a single calibration equation per variable per year. For the multilocation yield tests the calibration statistics for IVDMD in 2001 and 2002, respectively, were standard error of prediction (SEP) = 1.70 and 1.17 g kg^{-1}, R^2 = 0.90 and 0.94. Calibration statistics for N in 2001 and 2002, respectively, were SEP = 0.04 and 0.04 g kg^{-1}, R^2 = 0.99 and 0.99. In the pasture trial, calibration statistics for IVDMD in 2004 and 2005, respectively, were SEP = 1.13 and 1.23 g kg^{-1}, R^2 = 0.96 and 0.98. Calibration statistics for N in 2004 and 2005, respectively, were SEP = 0.02 and 0.06 g kg^{-1}, R^2 = 0.99 and 0.99.

Characteristics

Agronomic and Botanical Description

Warrior is similar in maturity to Oto and Scout in both swards and space-planted nurseries (Table 4). Both are about 7 d earlier in heading date (date when inflorescence is fully exerted from the boot) than Rumsey and Osage. Warrior is about 6 d later in maturity than Nebraska 54 when evaluated in swards. Warrior can be distinguished from its parent cultivar Oto by glume color frequencies. Oto parent plants were selected for brown glumes. In comparison to other indiangrass cultivars, Oto has a low percentage of plants with black or dark brown glumes (<10%). Warrior has a lower frequency of plants with dark brown or black glumes (<5%) and has a greater percentage of plants with yellow-brown glumes than Oto (approximately 40% versus 20%). Other plants of Warrior or Oto have brown or light brown glumes. Warrior can be distinguished from Nebraska 54 and Scout because approximately 20% of the plants in Nebraska 54 and Scout have black glumes. In replicated sward trials, Scout was 6 d earlier in heading date (date when inflorescence is fully exerted from the boot) than Nebraska 54 but is similar in heading date in space-planted nurseries. Scout is 8 d earlier in heading date than Rumsey and Osage and is similar in heading date to Oto and Warrior. Scout is about 20 d later in maturity than Holt and 10 d later in maturity than Chief. Scout can be distinguished from its parent cultivar by the difference in heading date in solid stands and glume color frequencies. Scout differs from Nebraska 54 in the number of plants with brown (40–50% versus 20–30%) and yellow-brown (0–10% versus 10–20%) glumes, respectively. Both cultivars have similar percentage of plants with black glumes (approximately 20%) and light brown glumes (25–40%). Chief is 10 d later in heading date (date when inflorescence is fully exerted from the boot) than Holt in swards. Its heading date is 3 d earlier than the cultivar Nebraska 54 and 6 d earlier than Scout, Oto, and Warrior when evaluated in swards.

Forage Yield and Quality

In the over locations analysis of variance (data not shown) of the forage trials, strain × location interaction effects were not significant for all traits except for Harvest 2 yield indicating consistency of ranking of strains for traits over locations. Warrior, Scout, and Chief all had significantly greater Harvest 1 yield than Holt and Rumsey

Table 4. Means of indiangrass cultivars and experimental strains averaged over three locations (Clay Center, Mead, and Concord, NE) for forage yield, in vitro dry matter digestibility (IVDMD), N concentration, and heading date averaged for two years of harvest (2001–2002). Heading date measured as day of year (DOY).

Cultivar or experimental strain	Origin HZ†	Harvest 1			Harvest 2 (regrowth)‡			Heading date§	
		Forage yield	IVDMD	N¶	Forage yield	IVDMD	N	Swards	Spaced plants
		Mg ha^{-1}	g kg^{-1}		Mg ha^{-1}	g kg^{-1}		DOY	
Holt	HZ 4	9.8	642	12	1.1	551	7	222	219±7
Chief (Holt × Oto Early C2)	HZ 4/5	**10.5**	644	12	**1.6**	564	8	232	
Nebraska 54	HZ 5	10.5	651	12	2.0	570	7	235	241±7
NE 54 Seedling vig. C4	HZ 5	10.4	647	12	1.8	570	7	234	
Scout (NE 54 C2)	HZ 5	10.6	652	12	2.0	563	7	241	241±7
Holt × Oto Late C3	HZ 4/5	10.3	649	12	2.0	569	7	238	237±7
Oto	HZ 5/6	10.6	650	12	2.0	576	7	242	242±7
Warrior (Oto C3)	HZ 5/6	10.3	**662**	13	1.8	572	8	241	239±7
Rumsey	HZ 5/6	9.0	656	13	2.2	616	10	249	
Osage	HZ 6	9.9	646	12	2.0	580	8	249	
LSD 0.05		0.5	6	1	0.4	17	1	4	4#

†USDA Plant Hardiness Zone (HZ) of origin of germplasm used to develop the cultivar or experimental strain.

‡Harvest 2 or regrowth yields were taken only in 2002 because of drought in 2001.

§Heading date (R2 stage) in sward plots was determined in 2004 when plots were not harvested. Heading date on plants spaced on 1.1-m centers in rows also were taken in 2004 on about 50 plants of strains for which mean and ± standard deviation are listed.

¶N g kg^{-1} × 6.25 = protein g kg^{-1}.

#Confidence interval (95%) for all stains in the spaced planted nursery was ±2 d. Heading date differences > 4 d are significantly different determined by non-overlapping confidence intervals (Steel and Torrie, 1960). All heading dates were taken at Mead, NE.

averaged over all three locations (Table 4). Chief had significantly greater first and second harvest forage yield averaged over all locations than Holt which is the only currently available HZ 4 cultivar (Table 4). At Clay Center, Scout had significantly greater forage yield than all other tested cultivars and experimental strains (Table 5). The Clay Center site is representative of the western part of PAR 251-5 and PAR 332-5 where Scout and its parent cultivar, Nebraska 54, are best adapted. It did not differ from Nebraska 54 for forage yield and IVDMD at the other locations. Warrior had significantly greater Harvest 1 IVDMD than all other cultivars averaged over locations and years (Table 4). Warrior did not differ from its parent cultivar Oto and other HZ 5 cultivars for first-harvest forage yield, but it had significantly higher first-harvest forage yield than the other HZ 6 cultivars, Rumsey and Osage ($P \leq 0.10$). Two other experimental strains, NE 54 Seedling vigor C4 and Holt × Oto Late C3, which were included in the trial, had lesser forage quality or forage yields in comparison with the strains that were released as cultivars (Tables 4 and 5).

Grazing Trial—Beef Cattle Gains

Warrior was compared with Oto in a replicated grazing trial located near Mead, NE, during 2003 and 2004. Warrior and Scout pastures established rapidly and were ready to graze 1 yr after seeding. In the two years of the grazing trial, cattle grazing the Warrior pastures had 7% ($P \leq 0.07$) greater average daily gain and beef production per hectare than cattle grazing the Oto pastures (Table 6). On the basis of an economic analysis, the increased gain by cattle grazing Warrior pastures in comparison with Oto pastures resulted in an increase of $21 per ha net return. Cattle grazing the Scout pastures had 3.5% ($P \leq 0.13$) greater average daily gain and 4.8% ($P \leq 0.016$) greater beef production per hectare than cattle grazing the Nebraska 54 pastures (Table 6). On the basis of an economic analysis, these small improvements in increased gain by cattle grazing Scout pastures in comparison with Oto pastures resulted in an increase of $13 per ha net return. The beef production values for both Warrior and Scout underestimate the total beef production capability and economic value of the cultivars because regrowth was not grazed.

DISCUSSION

Recommended Areas of Use

The lack of precise boundaries in natural environments should be recognized. Both Bailey's ecoregion concept and plant hardiness zones attempt to define areas of plant adaptation on the basis of environmental factors that gradually change across the landscape. Because of the gradual change in environmental factors that control plant growth, any system such as Plant Adaptation Regions (PARs) that provides discrete geographical boundaries on the basis of these factors is not absolute but requires judgment on the part of the users. Recently, extensive testing of switchgrass, another native prairie grass, has demonstrated that switchgrass cultivars should not be moved more than one hardiness zone north or south of their origin to avoid winter damage to stands or reduction in forage yield but can be moved east or west of the cultivar origin ecoregion based on field test results (Casler et al., 2007). Because indiangrass from the same latitude reaches maturity 3 to 4 wk later than switchgrass, experience indicates that in general indiangrasses can be moved about half a hardiness zone north of their origin hardiness zone.

The following recommended areas of use are based on test results to date, the parentage of the cultivars, the known adaptation range of the parent cultivars from their extensive use in field plantings, previous adaptation information as

Table 5. Means of indiangrass cultivars and experimental strains for Clay Center, NE, for forage yield, in vitro dry matter digestibility (IVDMD), and N concentration averaged over two years of harvest (2001–2002). Harvest 1 was taken when plants were in the elongation stage or pre-boot stage. Harvest 2 was taken after a killing frost.

Cultivar or experimental strain	Origin HZ†	Harvest 1			Harvest 2 (regrowth)‡		
		Forage yield	IVDMD	N	Forage yield	IVDMD	N
		Mg ha^{-1}	g kg^{-1}		Mg ha^{-1}	g kg^{-1}	
Holt	HZ 4	8.7	656	11	0.2	551	7
Chief (Holt × Oto Early C2	HZ 4/5	9.4	654	10	0.4	568	7
Nebraska 54	HZ 5	9.5	669	12	0.3	586	7
NE 54 Seedling vig. C4	HZ 5	9.4	659	10	0.2	598	7
Scout (NE 54 C2)	HZ 5	10.7	661	11	0.4	576	6
Holt × Oto Late C3	HZ 4/5	9.5	657	10	0.4	574	6
Oto	HZ 5/6	9.6	660	10	0.4	580	7
Warrior (Oto C3)	HZ 5/6	9.5	669	12	0.2	594	8
Rumsey	HZ 5/6	7.0	667	12	0.2	627	9
Osage	HZ 6	9.4	658	10	0.4	580	7
LSD 0.05		0.9	ns	1	ns	29	2

†USDA Plant Hardiness Zone (HZ) of origin of germplasm used to develop the cultivar or experimental strain.

‡Harvest 2 or regrowth yields were taken only in 2002 because of drought in 2001.

described above, and two decades of seed production experience with the breeding populations of these cultivars at the Agricultural Research and Development Center near Mead, NE. Warrior is best adapted to PAR 251-5 and upper PAR-6 (Fig. 1) while Scout is best adapted to the western part of PAR 251-5 and eastern PAR 332-5. On the basis of its parentage, Chief is best adapted to PAR 251-4 but also can be used in the eastern part of PAR 332-4. Seed production from Warrior and its progenitor populations was not successful in some years at the Mead, NE, site because early frosts limited seed ripening. Seed production on Scout and Chief in contrast has been fully successful at this location. On the basis of this information, use of Warrior in Hardiness Zone 4 is questionable, but Scout performance at the Concord site indicates it can be successfully used in Hardiness Zone 4. In its area of adaptation, Warrior produces forage with high IVDMD that results in improved animal gains when utilized by beef cattle in well managed grazing systems. Scout produces significantly greater forage yields than other adapted indiangrass cultivars when grown for hay in the western part of its adaptation region. Chief produces significantly greater forage yields than the other available HZ 4 cultivars. In the regions where they are adapted, these cultivars also could be used with other grasses in multispecies mixtures to produce biomass for bioenergy.

Seed Availability

Warrior, Scout, and Chief are stable, improved random-mated populations and will be maintained and increased accordingly. The seed classes will be Breeder, Foundation, and Certified. Breeder seed will be jointly maintained and produced by USDA-ARS and the University of Nebraska-Lincoln with random-mated, isolated increase nurseries originating from the Syn 2 breeder seed. Foundation seed production of the cultivars will be managed by Husker Genetics, the Foundation Seed Division of the University of Nebraska-Lincoln, Lincoln, NE. Foundation seed will be made available for certified seed production on a non-exclusive basis to seed producers who contractually agree to produce and market

Table 6. Mean beef cattle yearling average daily gains (ADG), gain per hectare, and mean net return per hectare for fertilized indiangrass pastures at Mead, NE, in 2004 and 2005.

Strain	ADG	Gain ha^{-1} year^{-1}	Mean net return†
	kg animal^{-1} d^{-1}	kg	$ ha^{-1} yr^{-1}
Oto	0.82	387	255
Warrior (Oto C3)	0.89	418	276
Paired *t* test Prob > *t*	0.07	0.07	
Nebraska 54	0.86	400	264
Scout (NE 54 C2)	0.89	419	277
Paired *t* test Prob > *t*	0.13	0.16	
SE	0.03	13	

†Net return ($ ha^{-1} yr^{-1}) calculated as mean body weight gain ha^{-1} × $0.66 kg^{-1} gain (Mitchell et al., 2005). Net return included 112 kg N ha^{-1} yr^{-1} fertilizer costs.

Warrior, Scout, or Chief seed only as certified seed under the cultivar name. A technology development and transfer fee will be assessed by the University of Nebraska. Certified seed production for Warrior will be restricted to USDA Plant Hardiness Zones 5 and 6 where the cultivar is adapted. Certified seed production for Scout will be restricted to the USDA Plant Hardiness Zone 5, where the cultivar is best adapted. Certified seed production for Chief will be restricted to the USDA Plant Hardiness Zone 4 or upper Plant Hardiness Zone 5, where the cultivar is best adapted. Small quantities of seed for research purposes may be obtained from USDA-ARS, Lincoln, NE. A seed sample has been deposited in the USDA-ARS National Center for Genetic Resources Preservation and seed is freely available to interested researchers.

Acknowledgments

Individuals contributing to the development and evaluation of Warrior were K.P. Vogel (breeding, sward, and grazing trials), R.B. Mitchell (sward and grazing trials), Herman Gorz (breeding, first cycle), USDA-ARS; Francis Haskins (breeding, first cycle), University of Nebraska. Individuals contributing to the development and evaluation of the cultivar Chief include K.P. Vogel (breeding and sward trials), L.C. Newell (breeding), and R.B. Mitchell (sward trials), USDA-ARS. Individuals contributing to the development and evaluation of Scout

were K.P. Vogel (breeding, sward, and grazing trials) and R.B. Mitchell (sward and grazing trials). T.J. Klopfenstein, G. Erickson, and B.E. Anderson, University of Nebraska, Lincoln, NE, participated in the Warrior and Scout grazing trial.

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